ADMINISTRATIVE INFORMATION

1.	**Project Name:**	Ultrasonic Processing of Materials	
2.	**Lead Organization:**	The University of Tennessee Materials Science and Engineering Department 434 Dougherty Engineering Bldg. Knoxville, Tennessee 37996-2200	
3.	**Principal Investigator:**	Thomas T. Meek (865) 974-0940/(865) 974-4115/ tmeek1@utk.edu	
4.	**Project Partners:**	DOE-HQ contact: (303) 275-4740, mehesh.jha@go.doe.gov	Mahesh C. Jha, Ph.D.
		Industry contact:	Secat, Inc., Subodh Das, (859) 514-4955, skdas@engr.uky.edu, skdas@secat.net Carpenter Technologies Corp., Gernant E. Maurer, (610) 208-3700, gmaurer@cartech.com
		National Laboratory Participants:	Qingyou Han (865) 574-4352 hanq@ornl.gov
5.	**Date Project Initiated:**	10/1/2001, FY 04	
6.	**Expected Completion Date:**	9/29/04	

PROJECT RATIONALE AND STRATEGY

7. Project Objective: The objective of this work is to develop core principles and establish quantitative basis for nucleation, growth, and fragmentation processes during alloy solidification in an acoustic field. Also, this study should provide tools for producing novel and fine-grained alloy microstructures.

8. **Technical Barrier(s) Being Addressed:** None

9. **Project Pathway**: None

10. Critical Technical Metrics:

- Demonstrate grain refinement of aluminum alloys-Go/No Go criterion
- Demonstrate grain refinement of 4340 steel-Go/No Go criterion

PROJECT PLANS AND PROGRESS

11. Past Accomplishments:
Over the past year the effects of cooling rate on final microstructure when acoustic energy is applied was studied. First, the 3004 aluminum alloy was raised to between 680-700^{0}C (about 30^{0}C above the liquidius). With the furnace turned off acoustic energy was applied by inserting the probe into the melt. Acoustic energy was stopped and the probe withdrawn from the melt at about 90% solid fraction (615^{0}C).

The crucible was then allowed to furnace cool (a slow cooling rate). Runs were made at different temperatures near and below the liquidius and time of acoustic application varied. Application times were 5, 10 and 20 seconds.

Microstructures which resulted from this approach did not vary appreciably from those which had no acoustic power applied.

Secondly, the 3004 alloy was allowed to cool outside of the furnace after acoustic energy was applied (a fast cooling rate). Again, the observed microstructures did not vary much from those which had no acoustic energy applied.

Thirdly, the 3004 alloy was allowed to cool very slowly by placing a small crucible that had been exposed to 20kHz acoustic energy into a larger crucible containing molten Δ356. Otherwise, the same conditions as in the first case above were used. Again, very little difference between acoustic and conventional samples was seen.

The fourth approach was to apply 20 kHz acoustic energy to molten A356 aluminum (at about 670^0C). The probe was placed onto the outside of the crucible and acoustic energy applied during the cooing of the melt. Again, application times were 5,10, 20 and 40 seconds. After the melt reached a given temperature, it was then poured into a copper mold and then allowed to cool very quickly. Here a great difference was observed between the samples that had acoustic energy applied and those processed conventionally. This is shown in figures 1 and 2.

Lastly, 4340 steel was melted in a graphite mold with 20 kHz acoustic energy applied onto the outside surface of the crucible.

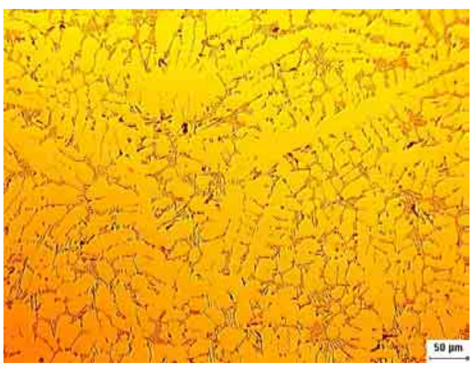

Figure 1 As cast A356 aluminum without the application of acoustic energy

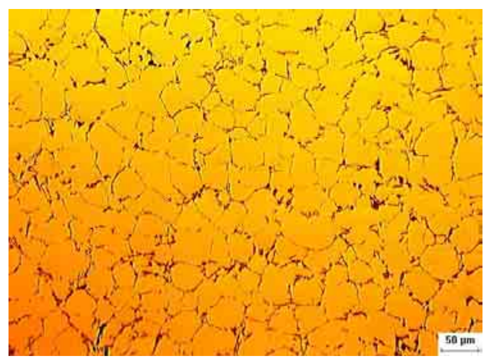

Figure 2 As cast A356 aluminum with the application of 20 kHz acoustic energy for 30 seconds and rapidly cooled in a copper mold

Acoustic energy was applied for 5,10, 20 and 40 seconds. The melt then was allowed to cool very quickly. Results show a significant difference between the conventionally processed samples and those that had acoustic energy applied. This is seen in figures 3-5.

Figure 3 As cast microstructure of 4340 steel without acoustic energy. Cast temperature 1525^0, magnification 200x

Figure 4 4340 steel with 20 kHz acoustic energy applied for 20 seconds. Cast temperature 1516^{0}C,

Figure 5 4340 steel with 20 kHz acoustic energy applied for 20 seconds. Cast temperature 1548^{0}C, Magnification 200x

During this time we finished the experimental matrix of metal mold casting with ultrasonic vibrations on aluminum alloy **A356**. Fig. 6-7 show the resulting microstructures obtained for this alloy processed in an acoustic field. Fig. 6 shows the microstructure of A356 alloy with no applied acoustic energy while fig. 7 shows the microstructure resulting from the exposure to ultrasonic energy. The amplitude of incident power was 90% and the processing time was (30 seconds). We characterized the microstructures using SEM and image-pro plus (an image processing software). Initial results show that the higher the amplitude used, the more uniform microstructure (totally globular refined grains) was obtained.

Then we used a 5% HF solution to etch the samples for from 2~10 min. A very substantial difference was seen by microscope using 50 X ~ 400 X magnification on the samples without ultrasonic treatment and with ultrasonic treatment. Without ultrasonic processing, dendrites (Fig. 6) were fully developed in the samples and clearly seen under the microscope. On those samples treated with ultrasonic vibrations, we confirmed the uniformly distributed globular grains by SEM. The secondary phase changes observed were due to their exposure to ultrasonic energy injected into the molten material during solidification.

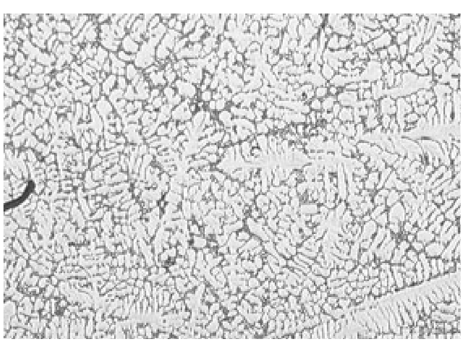

Fig. 6 A356 alloy: Without ultrasonic vibration, cast temperature 630^{0}C, magnification 5×, after etching with 5%

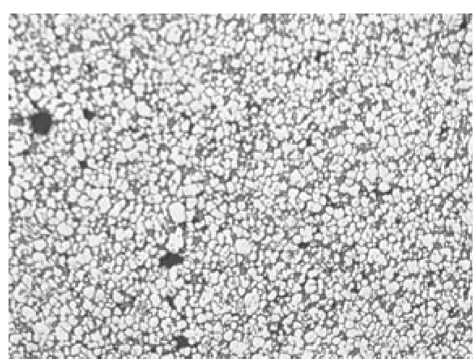

Fig 7 A356 alloy exposed to acoustic energy at 630^{0}C for 30 sec, magnification 5x, after being etched with 5% HF.

The ultrasonic experiments were also performed on two industrial aluminum alloys: 6061 and 6063. Partial phase diagrams of these alloys were developed. These alloys were provided by Secat Inc. and Ohio Valley Inc. as industrial in-kind. Golbular grains were obtained in these two alloys as well.

Using these compositions we did a thermodynamic simulation with pro-cast and got the phase diagram and the solid fraction- temperature curve of these alloys. The melting point of 6063 is 657°C and the casting temperatures for this alloy were 670^0C, 690^0C, 710^0C, and 730^0C. A blank sample was cast at 690^0C. The ultrasonic amplitude was 100% and the output power was 10-15% of full power. The processing time was 60 seconds. These samples will be characterized during the next quarter.

12. **Future Plans:** The included list gives the milestones for this project. This project is due to end 9/29/04. All of the tasks are on schedule to be completed as noted in the milestone list. Task 4-8 are yet to be completed but are on schedule to be completed by 9/29/04.

- Task 1 Experimental Apparatus, Completed 3/31/02
- Task 2 Degassing Al melts, Completed 3/31/03
- Task 3 Thermodynamic Modeling, Completed 6/30/03
- Task 4 Solidification of Alloys using ultrasonic energy, Planned completion 9/30/04
- Task 5 Characterization of solidification microstructures, Planned completion 9/30/04
- Task 6 Determination of fundamental mechanisms, Planned completion 8/31/04
- Task 7 Industrial applications of results, Planned completion 9/30/04
- Task 8 Reports and publications, Planned completion 9/30/04

13. **Project Changes:** None

14. **Commercialization Potential, Plans, and Activities:**
The aluminum industry will use this technology to reduce processing cost. In recent discussions we have had with SECAT the current status of this work was reviewed and the application of this research to the aluminum industry was addressed. Currently two papers have been presented at conferences and two papers have been accepted by journals for publication.

15. Patents, Publications, Presentations:
Patent Application: “Method and Apparatus for Semi-Solid Material Processings”
Presentation/Publications: “Ultrasonic Solidification of aluminum A356 Alloy,” X. Jian, H. Xu, T.T. Meek, S. Viswanathan, and Q. Han, The Third International Conference on Light Materials for Transportation Systems (LiMAT-2003), p. 23, Nov. 2-6 (2003), Honolulu, Hawaii

“Solidification of Aluminum Alloy A356 Under Ultrasonic Vibration,” X. Jian, Q. Han, H. Xu and T.T. Meek, T.T., *Solidification of Aluminum Alloys*, eds. M.G. Chu, D.A. Granger, and Q. Han (Warrendale, PA: The Minerals, Metals & Materials Society, 2004), pp73-79.

“Investigation of Ultrasonic Degassing in Molten Aluminum A356 Alloy,” Xu, H., Jian, X., Han, Q, Meek, T.T., Light Metals 2004 Annual Meeting, March 14-18, 2004, Charlotte, North Carolina, Proceedings Edited by A.T. Tabereaux, TMS.